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IDA MEMORANDUM REPORT M-14

COST-ESTIMATING RELATIONSHIPS FOR TACTICAL COMBAT AIRCRAFT

Joseph W. Stahl
Joseph A. Arena
Mark I. Knapp

November 1984

Prepared for

Office of the Under Secretary of Defense for Research and Engineering

INSTITUTE FOR DEFENSE ANALYSES
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document presents four separate cost-estimating relationships (CERs): one each for RDT&E and procurement for helicopters and fixed-wing aircraft used in tactical air missions. The CERs are functions of such major characteristics as weight, thrust/weight ratio, speed and year of IOC.

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COST-ESTIMATING RELATIONSHIPS FOR TACTICAL COMBAT AIRCRAFT

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Task T-3-150

PREFACE

This memorandum report is part of a broader continuing program at the Institute for Defense Analyses under the technical cognizance of Dr. Paul J. Berenson, Special Assistant for Assessment, Office of the Under Secretary of Defense for Research and Engineering, under Task Order T-3-150, dated 23 December 1982. The broader effort, "NATO/Warsaw Pact Acquisition Balance," has as its purpose the development of an overview of the US/USSR technology and acquisition balance.

SUMMARY

IDA Paper P-1790, Joseph A. Arena, Margaret R. Kiselick, Joseph W. Stahl, A Comparison of US and USSR Tactical Aviation Activities (U), December 1984 (SECRET), compares trends of the production quantities, average chronological age, average technological age, force weights, research, development, test and engineering, procurement and inventory costs for US and USSR tactical combat aircraft. This memorandum report presents cost-estimating relationships developed to produce these data.

New cost-estimating relationships were needed:

- to update earlier methodologies for calculating US aircraft data, and
- to expand the methodology so that Soviet aircraft could be assessed by using generally observable characteristics, since detailed information may often not be available.

Four cost-estimating relationships were developed:

- research, development, test and engineering for both helicopters and fixed-wing fighter and attack aircraft, and
- procurement (and inventory cost when combined with force levels) for both helicopters and fixed-wing fighter and attack aircraft.

So that US and Soviet aircraft comparisons could be made, as a standard, the cost of Soviet aircraft acquisition was set to be the same cost the United States would incur had the acquisition been that of the US military-industrial organization.

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A. INTRODUCTION

This document presents Cost-Estimating Relationships (CERs) that were developed as part of a broader study [1] that compares various attributes of US and USSR tactical aviation aircraft forces. In this introduction two topics are discussed: the scope of the overall study for which the techniques were developed and an overview of the cost estimating methodology.

Separate publication of this paper provides the CERs to a wider audience than that of the parent study for use when relatively few aircraft characteristics are available. Since trends rather than absolute values were emphasized in the study for which these CERs were developed, the CERs were validated for groups of aircraft. As such, these CERs cannot be expected to approximate closely the cost of a particular model/design/series aircraft. They may be used, however, to provide aggregate checks of estimates derived by more detailed analyses or when aggregate estimates--rather than precise estimates of particular aircraft--would be useful.

1. The Tactical Aircraft Comparison

The US-USSR comparison of tactical aviation for which the CERs in this paper were developed was limited to those combat aircraft that operate at or beyond the forward edge of the battle area. It included those aircraft that attack enemy surface and air forces as well as the following aircraft types--observation, reconnaissance, electronic warfare, early warning, and tankers (see Figure 1).

MISSIONS AND FUNCTIONS

- Attack Enemy Surface Forces
  - In contact
  - In rear
- Attack Enemy Tactical Air Forces
  - In air
  - On ground
- Observation and Reconnaissance

TACTICAL COMBAT AIRCRAFT TYPES

Fighter
Attack (or Fighter/Bomber)
Bomber
Tanker
Reconnaissance
Observation
Electronic Warfare, Early Warning, C^2

Services

US[a]	USSR
Army	Frontal Aviation
Navy/Marines	Naval Aviation
Air Force	

[a]Includes Guard and Reserves; no Soviet equivalent.

Figure 1. DEFINITION OF TACTICAL COMBAT AIRCRAFT

The study itself included comparisons of age, weight, acquisition cost (that is, procurement and RDT&E), and inventory cost. It covered the years 1965 through 1990 and emphasized trends for US and USSR forces and costs. Thus, the CERs were needed to estimate RDT&E and procurement costs. Further, the procurement costs were also used, when combined with force levels, to estimate inventory cost.

2. Estimating Techniques

It was necessary to develop new CERs for two reasons: first, earlier CERs were out of date in that they did not

include aircraft introduced into the force in the 1970s and 1980s; the F-14, F-15, F-16, F/A-18, A-10 and AV-8B. Second, estimating costs of Soviet aircraft required CERs that were based on the limited number of characteristics deducible from observation. Typical CERs developed in the past for US aircraft make use of subsystem characteristics, rather than overall aircraft characteristics, in order to estimate the costs of airframe, engine, electronics, and weapons. Such CERs require more detail than is deducible from observation of Soviet aircraft.

The CERs represent estimates of what it would cost the US to develop and produce the aircraft, thus allowing a comparison of aggregations of US and USSR aircraft in a uniform way. The CERs are based, therefore, on US experience with similar aircraft, using prevailing US dollar prices for materials and labor (including overhead and profit), as well as US military-industrial organization, acquisition practices, and production technology. The results do not represent the cost to the USSR but, rather, the probable cost to the US of developing and producing the Soviet force. Such calculations are of value in making comparisons between the two countries at a particular point in time and examining the trends and major changes in the sizes of the US and Soviet efforts over time.

The major characteristics used in the development of the CERs were total maximum thrust at sea level, DCPR weight[1], thrust/DCPR weight ratio, speed and year of IOC. For RDT&E costs only, the number of flight test aircraft was also used (see Table 1 for values for fixed-wing aircraft).

The procedures followed for the two categories were as follows:

- RDT&E Costs - CERs were developed and validated for estimating the annual RDT&E costs for both fixed-wing and

[1]For a definition of DCPR weight see Table 1, footnote b.

Table 1. FIXED-WING AIRCRAFT CHARACTERISTICS AND COSTS

AIRCRAFT	Thrust (pounds[a])	DCPR Weight (pounds[b])	Speed (knots[c])	IOC (Year[d])	Cost ($ Millions 1985) R&D[e]	Flyaway[f]
Attack						
A-7A	11,400	1,600	594	1967	347	6.7
AV-8B	21,500	7,600	600	1983	1,171	n.a.
A-10	19,200	14,800	430	1977	970	6.9
AC-119[g]	17,500	27,800	250	1962	n.a.	5.1
AC-130[h]	40,500	51,500	330	1965	n.a.	15.0
Fighter						
F-4A	34,000	17,200	1,218	1961	n.a.	10.2
F-5A	8,200	5,700	800	1964	n.a.	2.1
F-14A/B	41,800	26,500	1,380	1973	3,477	28.1
F-15	47,600	18,400	1,440	1975	5,136	18.2
F-16	23,800	9,000	1,150	1980	1,766	11.4
F/A-18	33,400	14,300	980	1982	3,684	24.2
F-100A	11,700	12,100	709	1957	n.a.	4.6
F-101A	30,000	14,700	870	1958	n.a.	9.1
F-102A	16,000	12,100	680	1957	n.a	4.9
F-104A	11,000	8,100	1,150	1957	n.a.	5.3
F-105A	24,000	18,500	1,200	1959	n.a.	10.3
F-106A	24,500	15,600	1,150	1959	n.a.	12.6
F-111A	37,000	33,300	1,260	1968	5,379	27.4
Tankers						
KC-10	163,492	199,990	520	1981	n.a.	46.4
KC-97G[g]	44,700	60,000	350	1964	n.a.	7.5
KC-135R	55,000	70,500	530	1962	n.a.	10.9
Electronic Warfare, Early Warning, C2						
E-2C[g]	21,400	23,100	320	1974	n.a.	36.6
E-3A	83,994	13,109	470	1977	n.a.	94.6
EA-6A	17,000	20,600	550	1965	693	
EC-121S[g]	33,953	63,000	250	1967	n.a.	21.8
Observation						
OV-10A[g]	3,600	5,200	250	1967	n.a.	1.3

SOURCES: References [4-15]

Notes: See following page.

NOTES:

[a]Thrust (total maximum thrust at sea level in pounds) was obtained directly for jet powered aircraft. For piston engine/propeller powered aircraft, thrust was calculated at 2.49 pounds per shaft horsepower; for turbine engine/propeller powered aircraft, it was calculated at 2.34 pounds per equivalent shaft horsepower.

[b]Defense Contractor's Planning Report (DCPR) weight is defined as the empty weight of the airplane less (1) wheels, brakes, tires and tubes, (2) engines, (3) starter, (4) cooling fluid, (5) rubber or nylon fuel cells, (6) instruments, (7) batteries and electrical power supply and conversion equipment, (8) electronic equipment, (9) turret mechanism and power operated gun mounts, (10) remote fire mechanism and sighting and scanning equipment, (11) air conditioning units and fluid, (12) auxiliary power plant unit, and (13) trapped fuel and oil. In those cases where DCPR weight was not directly available, it was derived from empty weight by use of the following relationships [2]:

$$\mathrm{DCPR} = 0.0913(\mathrm{EW})^{1.177} \text{ for EW} > 50{,}000$$

$$\mathrm{DCPR} = 0.246\ (\mathrm{EW})^{1.096} \text{ for } 10{,}000 \leq \text{EW} \leq 50{,}000$$

$$\mathrm{DCPR} = 13.26\ (\mathrm{EW})^{0.674} \text{ for EW} < 10{,}000$$

where

DCPR = aircraft DCPR weight in pounds

EW = aircraft empty weight in pounds

[c]Maximum speed at best altitude in knots.

[d]Initial Operational Capability calendar year.

[e]Actual total RDT&E cost in millions of FY 1985 TOA dollars. Missing entries not available (n.a.).

[f]Cumulative average flyaway cost for 400 aircraft in millions of FY 1985 dollars TOA based on actual programs. Cumulative average learning curve slope of 0.92 was used, where 0.92 is the ratio of cumulative average costs at a production level of 2n units to the cumulative average cost at a production level of n units.

To calculate the cost of n aircraft from the cost in the table for 400 aircraft:

$$AC_n = C_1 n^{\left(\frac{\log \text{slope}}{\log 2}\right)}$$

$$AC_{400} = C_1 400^{\left(\frac{\log 0.92}{\log 2}\right)}$$

$$= C_1 400^{\left(\frac{-0.08338}{0.69314}\right)}$$

$$= C_1 400^{-0.12029}$$

$$= C_1 (0.48639)$$

Therefore

$$C_1 = \frac{AC_{400}}{0.48639}$$

For any n:

$$AC_n = \frac{AC_{400}}{0.48639} n^{-0.12029}$$

where

AC_n = Cumulative average cost of nth unit

C_1 = Imputed cost of first unit

[g]Reciprocating engines: One brake horsepower calculated at 2.49 lbs. of thrust.

[h]Gas turbine engines: One equivalent shaft horsepower calculated at 2.34 lbs. of thrust.

rotary-wing aircraft. A function was then developed to distribute the estimated total costs into annual costs. For validation, the resulting estimated annual costs were compared with actual costs of selected US fixed-wing and rotary-wing aircraft.

- Flyaway and Procurement Costs - CERs were developed and validated for estimating fixed-wing and rotary-wing aircraft flyaway costs. Factors for each Service were then developed to convert estimates of annual flyaway costs into estimates of procurement costs. The validation consisted of comparing these estimated procurement costs with actual aircraft procurement costs for each of the three US Services.

The data base used in the study included not only the types covered in the US-USSR comparison but, where possible, additional fixed-wing aircraft and helicopters that enriched the data base and allowed for more reliable estimates. In some cases it was necessary--because the aircraft or the program was unique--to use actual costs for US aircraft or to estimate USSR aircraft by direct analogy. This was particularly the case in the small number of RDT&E programs that were not carried to completion.

B. ESTIMATION OF ANNUAL RDT&E COSTS

1. Fixed Wing Aircraft RDT&E Costs

a. Development of CER for Total RDT&E. The characteristics of thrust, DCPR weight, speed and IOC date were selected for use in CERs to estimate RDT&E and flyaway costs (see Table 1 for values). The RDT&E and flyaway costs were normalized to FY 1985 TOA dollars using official DoD deflator indices [3].[2] Total RDT&E costs for seven fighter and attack aircraft (F-14,

[2]All costs in this paper are expressed as Total Obligational Authority (TOA) converted to 1985 dollars. They are referred to as 1985 dollars in the text, tables and figures.

F-15, F-16, F/A-18, F-111, A-7, and A-10) were regressed against various combinations of aircraft thrust, weight, speed, time (IOC year), and the number of flight test aircraft.[3] The best fit was RDT&E as a power function of DCPR weight, thrust/DCPR weight, and IOC date.

$$RD = 2.18(10)^{-6}(DCPR)^{2.0493}\left(\frac{THRUST}{DCPR}\right)^{1.7}(1.0239)^{IOC-78}$$

where

RD = Total RDT&E cost in millions of FY 1985 dollars TOA

DCPR = DCPR weight in pounds

THRUST = Total maximum thrust at sea level in pounds

IOC = Initial Operational Capability date represented by last two digits of calendar year

The degree of fit between estimated and actual total RDT&E cost of the seven aircraft is shown in Figure 2. The F-111 reported cost was underestimated and the reported costs of the F-14 and F-15 were overestimated. A possible explanation for the F-14 overestimate is that the F-14 did not require the development of a new engine. The F-14 engine was developed for the F-111. The F-111 underestimate may be due to its being the first swing-wing aircraft. Also, it uses an escape pod for the crew instead of ejection seats, and has a very sophisticated avionics suite to allow it to operate in the terrain following mode. The other aircraft are estimated more accurately.

b. Distribution of Annual RDT&E Costs. To indicate trends over time, it was necessary to spread the total program estimates to annual estimates. This was done by examining the

---

[3]RDT&E costs of the AV-8B and EA-6A, although shown in Table 1, were not included in the development of the CER. Neither was a full development program. The AV-8B is a variant of the British-developed Harrier. The EA-6A is a modification of the A-6A.

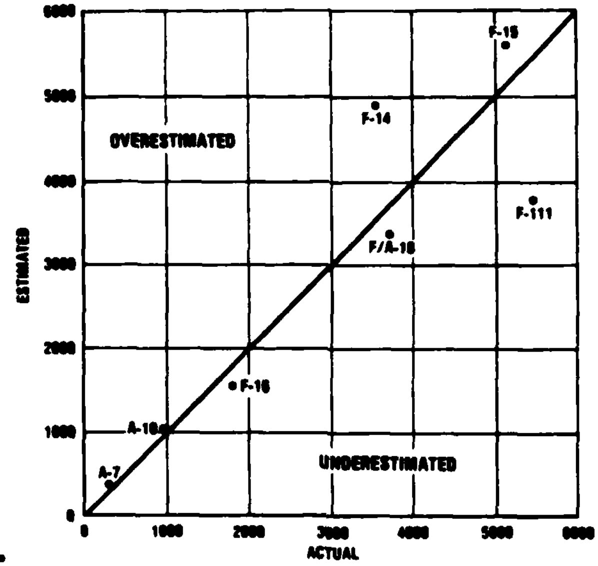

Figure 2. FIXED-WING FIGHTER & ATTACK AIRCRAFT RDT&E: ESTIMATED VS. ACTUAL COST--BY MODEL

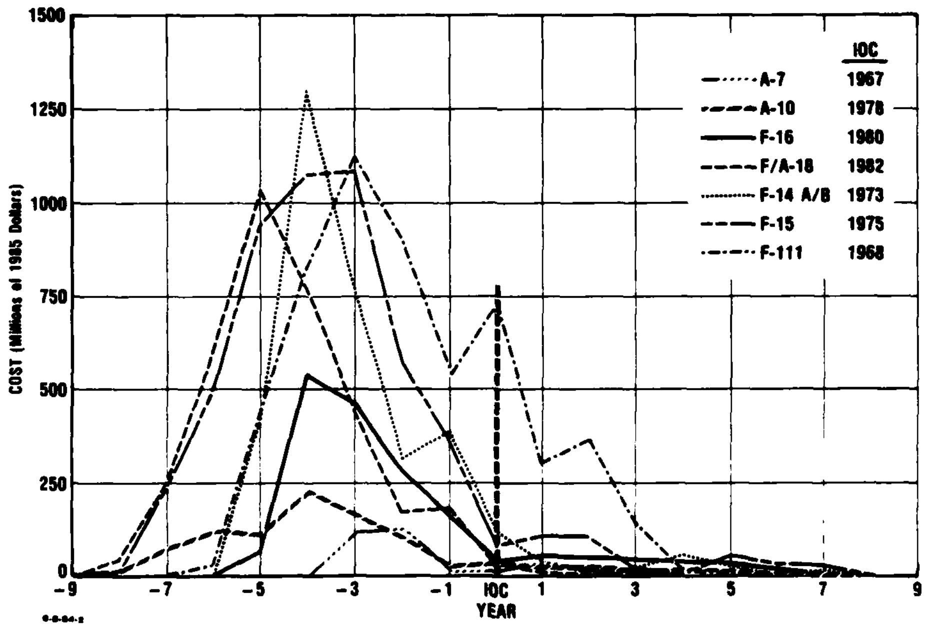

Figure 3. FIXED-WING FIGHTER & ATTACK AIRCRAFT RDT&E: ANNUAL COST RELATIVE TO IOC YEAR--BY MODEL

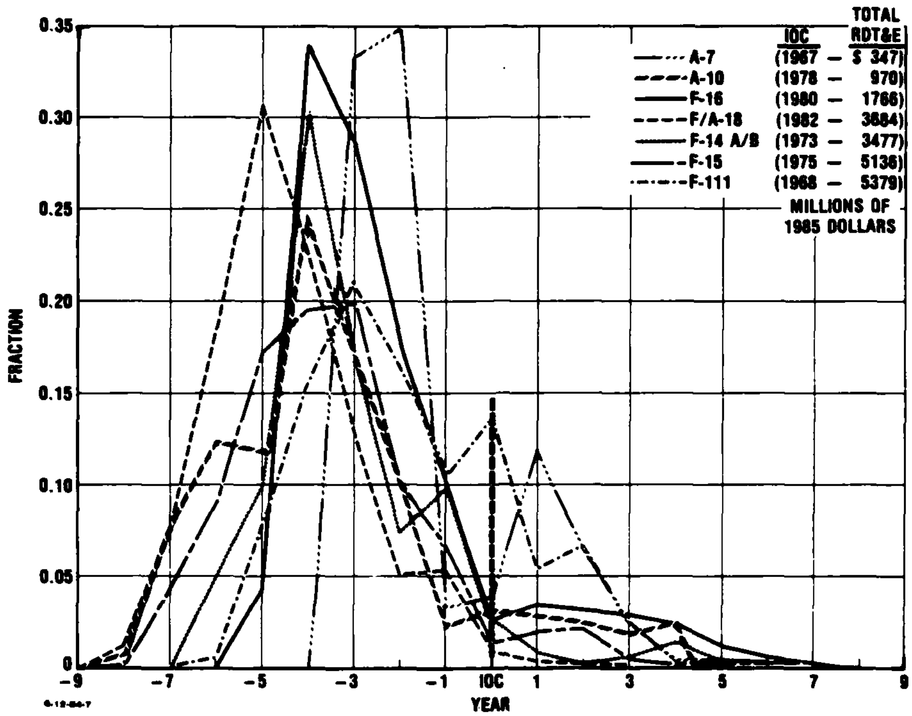

Figure 4. FIXED-WING FIGHTER & ATTACK AIRCRAFT RDT&E: ANNUAL COST AS FRACTION OF TOTAL, RELATIVE TO IOC YEAR--BY MODEL

Various composite distribution functions were then calculated (Figure 5). The $ AVERAGE function was determined by dividing the average annual dollar cost per aircraft (Figure 3) by the average total cost per aircraft. The function's mode occurred four years prior to the IOC year. The AVERAGE FRACTION function was determined as the average of the (equally weighted) fractional distributions shown on Figure 4. The THREE-YEAR MOVING $ AVERAGE is a smoothed version of the $ AVERAGE function. It gave the closest correlation to actual annual RDT&E costs for seven US fighter and attack aircraft programs and was, therefore, selected to distribute the estimated total RDT&E costs in annual dollars for fixed-wing aircraft in Table 2 (where year is relative to IOC).

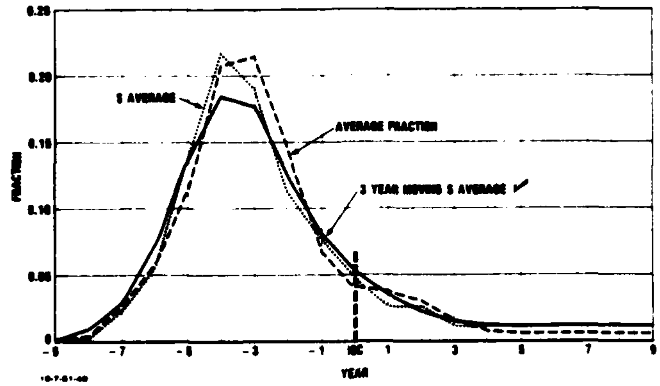

Figure 5. FIXED-WING FIGHTER & ATTACK AIRCRAFT RDT&E: ANNUAL COST AS FRACTION OF TOTAL, RELATIVE TO IOC YEAR--COMPOSITE

Table 2. FIXED-WING AIRCRAFT RDT&E COSTS: DISTRIBUTION AS A FRACTION OF TOTAL RELATIVE TO IOC YEAR

Year	Cost Fraction	Year	Cost Fraction
-8	.009	+1	.034
-7	.028	+2	.021
-6	.073	+3	.014
-5	.138	+4	.011
-4	.182	+5	.011
-3	.178	+6	.011
-2	.127	+7	.011
-1	.080	+8	.011
IOC	.051	+9	.010
		Total	1.000

c. <u>Validation of Estimating Procedures</u>. Annual RDT&E costs were estimated by first calculating the total RDT&E cost of each aircraft through the use of the RDT&E CER and then distributing the annual costs, relative to the aircraft's IOC year, by means of the THREE-YEAR MOVING $ AVERAGE distribution of Figure 5.

The individual aircraft costs were then summed by year to determine the annual total RDT&E cost by Service or mission category. The actual and estimated total annual aggregated RDT&E costs of the seven aircraft are shown on Figure 6. A comparison of the aggregated actual and estimated costs for all years is presented on Table 3. Although the estimated costs are quite different than actual costs for some years, the estimating procedure provided a good representation of the medium- and long-run trends of the actual costs.

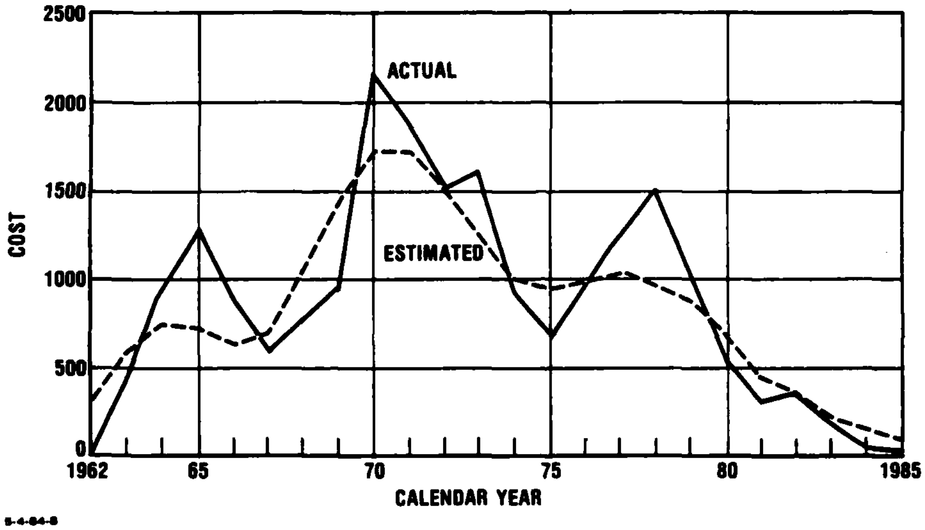

Figure 6. FIXED-WING FIGHTER & ATTACK AIRCRAFT RDT&E: ACTUAL AND ESTIMATED ANNUAL COST--COMPOSITE, 1962-1985

Table 3. FIXED-WING FIGHTER & ATTACK AIRCRAFT RDT&E COSTS, 1962-1987

Item	Cost ($ Millions 1985)
Actual Total	$ 20,759
Estimated Total	20,624
Difference (+ 0.07 percent)	$ + 155
Mean of Absolute Annual Differences	$203

2. Rotary-Wing Aircraft RDT&E Costs

a. Development of CER for Total RDT&E. Characteristics and costs of rotary-wing aircraft were collected and normalized to develop CERs for both RDT&E and flyaway costs (see Table 4). Because few RDT&E programs for helicopters could be identified as tactical combat aircraft (attack, observation and electronic warfare), utility and cargo helicopters were also included in the data base. It was found that CERs based on shaft horsepower (SHP) provided good estimates of RDT&E and flyaway costs: (a) if data were segregated into two groups ('attack' and 'other'); and (b) whether or not a program was a completely new one or a major modification. The CERs for total RDT&E and the data points used in deriving them are shown in Figure 7 as follows: Equation 1 is for new 'attack' programs, Equation 2 is for new 'other' programs, Equation 3 is for 'attack' major modifications and Equation 4 is for 'other' program modifications. Data points with the suffix "MOD" denote programs that were major modifications of earlier helicopters. These equations for total RDT&E can be stated, generally, as follows:

$$RD = 3.34(SHP)^{0.7}(2.0)^{ATK}(0.16)^{MOD}$$

where

RD = Total RDT&E Cost in FY 1985 $ Millions
SHP = Total Maximum Shaft Horsepower
ATK = 1 for Attack Helicopters; 0 elsewhere
MOD = 1 for Helicopter Modification; 0 elsewhere

The equations were used in developing operational rotary-wing aircraft RDT&E costs.

The relationship between estimated and actual total RDT&E costs of the same five helicopters is shown on a linear scale in Figure 8. The closeness of fit should not be interpreted as indicating a high degree of predictive capability, because of the small size and diversity of the sample used to generate the equations.

Table 4. ROTARY-WING AIRCRAFT CHARACTERISTICS AND COSTS

AIRCRAFT	Shaft Horsepower[a]	DCPR Weight[b]	IOC Year	Cost ($ Millions 1985) R&D	Flyaway[c]
Observation					
OH-6	320	850	1967	n.a.	0.28
OH-13	250	1,340	1960	n.a.	0.22
OH-23	200	1,350	1960	n.a.	0.21
OH-58	320	1,260	1970	n.a.	0.31
Attack					
AH-1	1,800			n.a.	1.8
AH-1Q/S MOD	1,400	4,300	1976	175[d]	n.a.
AH-1S	1,500	5,000	1980	n.a.	2.8
AH-1T	3,900	6,300	1978	n.a.	6.2
AH-64	3,100	10,430	1984	1,826[d]	6.91
Cargo					
CH-3	3,100	9,990	1964	n.a.	2.4
CH-46	2,500	10,800	1964	n.a.	3.2
CH-47A/D	5,000	15,710	1963	n.a.	3.2
CH-47D MOD	5,000	18,690	1984	191[d]	n.a.
CH-53	5,700	19,850	1965	n.a.	5.8
CH-53E MOD	13,100	26,470	1980	398[d]	13.7
CH-54	9,000	15,850	1967	n.a.	5.1
Utility					
UH-1	860	3,100	1960	n.a.	1.1
UH-60	3,100	8,725	1979	979[d]	5.0
Trainer					
TH-13	200	1,340	1965	n.a.	0.21

SOURCES: References [6, 12 and 16-19].

Notes on following page.

NOTES:

n.a. - not available.

[a]Total maximum shaft horsepower.

[b]In those cases where DCPR weight was not directly available, it was derived from empty weight by use of the following relationships [2]:

$$DCPR = 0.589(EW)^{1.033}$$

where

DCPR = aircraft DCPR weight in pounds

EW = aircraft empty weight in pounds.

[c]To calculate the cost of n aircraft:

$$AC_n = C_1 n^{\left(\frac{\log slope}{\log 2}\right)}$$

$$AC_{400} = C_1 400^{\left(\frac{\log slope}{\log 2}\right)} = C_1 400^{\left(\frac{\log 0.95}{\log 2}\right)}$$

$$= C_1 400^{\left(\frac{-0.051293}{0.69314}\right)}$$

$$= C_1 400^{-0.081236} = C_1 0.61463$$

or

$$C_1 = \frac{AC_{400}}{0.61463}$$

where

AC_n = cumulative average cost of nth unit

C_1 = imputed cost of first unit.

For any n aircraft:

$$AC_n = \frac{AC_{400}}{0.61463} n^{-0.081236}$$

[d]Actual total RDT&E cost is millions of FY 1985 TOA dollars.

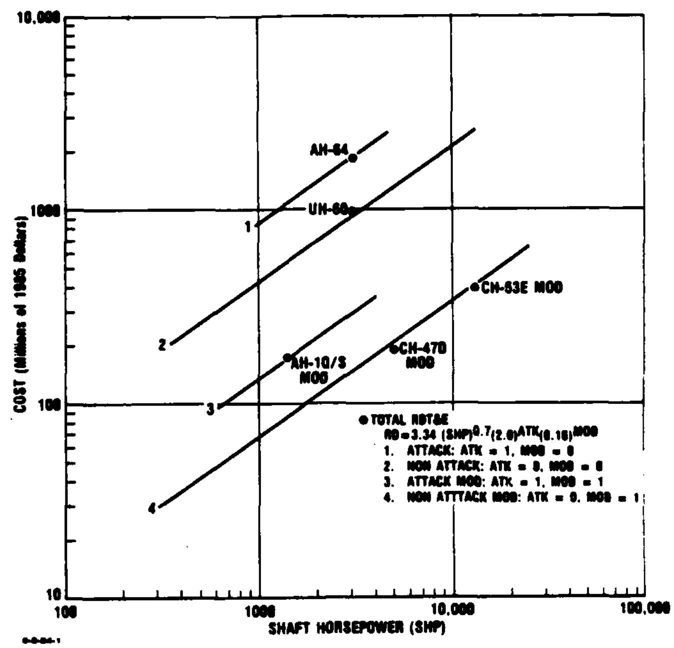

Figure 7. ROTARY-WING AIRCRAFT RDT&E: COST VS. SHAFT HORSEPOWER--BY MODEL

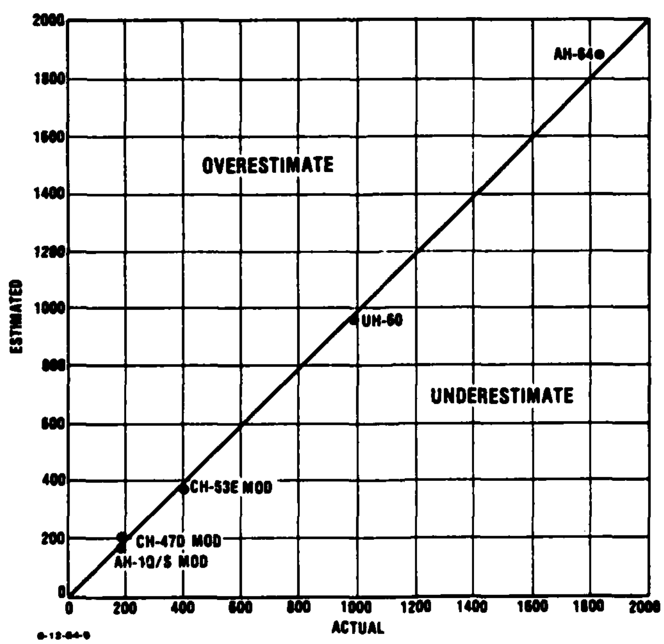

Figure 8. ROTARY-WING AIRCRAFT RDT&E: ESTIMATED VS. ACTUAL COST--BY MODEL (Millions of 1985 dollars)

b. Annual RDT&E Distribution Function. Figure 9 shows the annual RDT&E cost distributions of the five helicopter programs relative to the IOC year, and Figure 10 presents these costs as fractions of the total RDT&E cost for each program. Figure 11 presents the same three composite distribution functions as those discussed for fixed-wing aircraft. Again, the THREE-YEAR MOVING $ AVERAGE gave the closest correlation to actual annual RDT&E costs for five helicopter programs and was, therefore, selected to distribute the estimated total RDT&E costs in annual dollars for rotary-wing aircraft. The distribution, relative to IOC year, is shown in Table 5.

c. Validation of Estimating Procedures. The actual and estimated annual aggregated RDT&E costs of the five rotary-wing aircraft are shown in Figure 12. Comparisons of the actual and estimated total costs are shown in Table 6. The cost-estimating

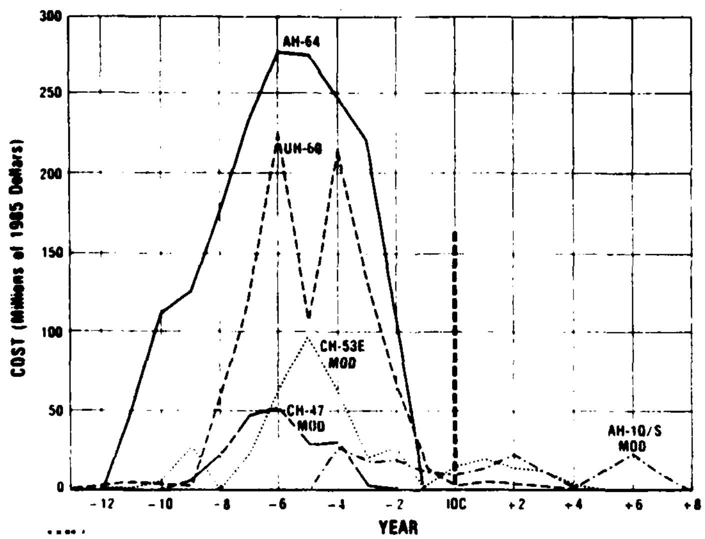

Figure 9. ROTARY-WING AIRCRAFT RDT&E: ANNUAL COST RELATIVE TO IOC YEAR--BY MODEL

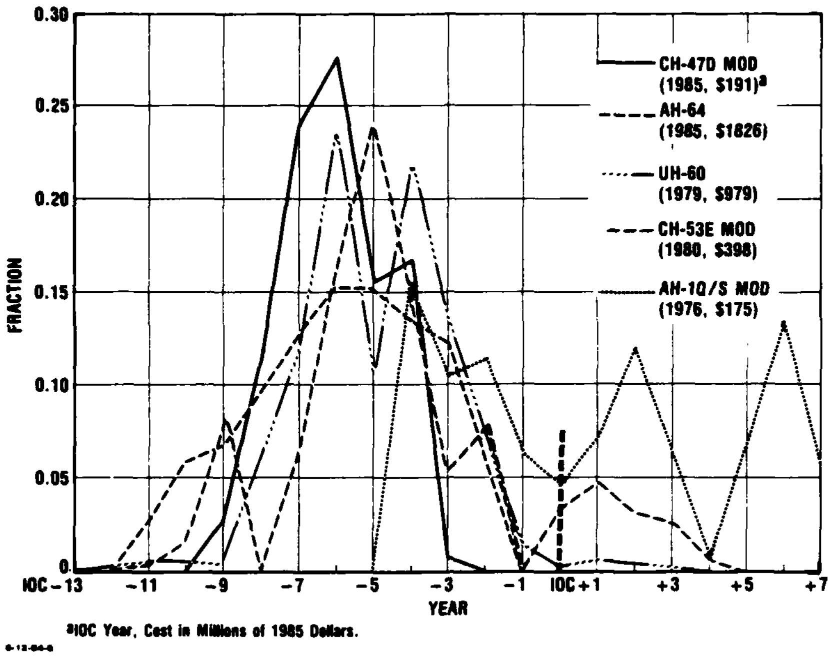

Figure 10. ROTARY-WING AIRCRAFT RDT&E: ANNUAL COST AS FRACTION OF TOTAL, RELATIVE TO IOC YEAR--BY MODEL

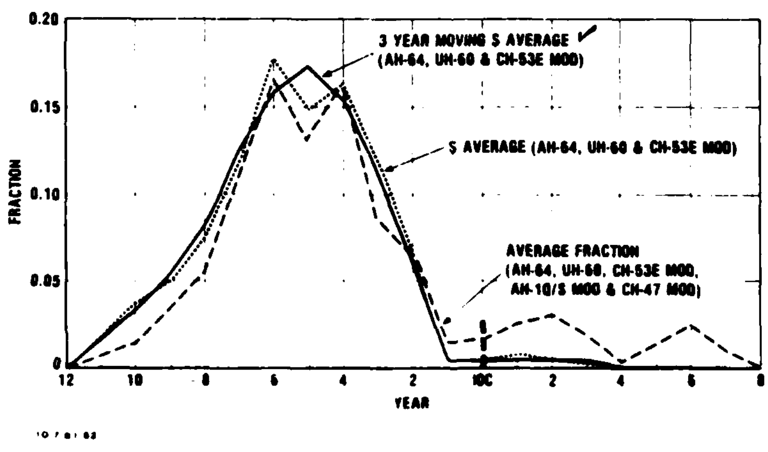

Figure 11. ROTARY-WING AIRCRAFT RDT&E: ANNUAL COST AS FRACTION OF TOTAL, RELATIVE TO IOC YEAR--COMPOSITE

procedure for rotary-wing aircraft yielded closer agreement between estimated and actual costs than the method for estimating fixed-wing aircraft costs. The estimating procedure satisfied

Table 5. ROTARY-WING AIRCRAFT RDT&E COSTS: DISTRIBUTION AS A FRACTION OF TOTAL RELATIVE TO IOC YEAR

Year	Cost Fraction	Year	Cost Fraction
-11	.018	-5	.174
-10	.035	-4	.154
- 9	.054	-3	.115
-8	.081	-2	.062
-7	.124	-1	.019
-6	.159	IOC	.005
		Total	1.000

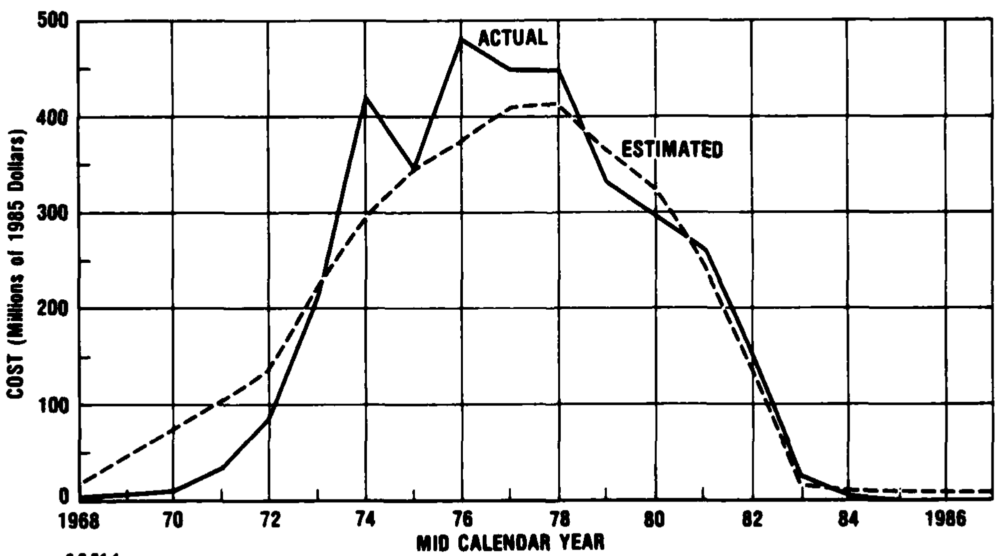

Figure 12. ROTARY-WING AIRCRAFT RDT&E COST: ESTIMATED VS. ACTUAL ANNUAL COST, 1968-1987

Table 6. RDT&E COST FOR FIVE ROTARY-WING AIRCRAFT, 1968-1987

Item	Cost (Millions 1985)
Actual Total Cost	$ 3,570
Estimated Total Cost	3,581
Difference (- 0.3 percent)	- $ 11
Range of Annual Differences	+$125 to -$67
Mean of Absolute Annual Differences	$ 31

the objective of producing estimates of rotary-wing aircraft annual aggregated RDT&E costs with trends that match actual costs.

C. ESTIMATION OF ANNUAL PROCUREMENT COSTS

1. Fixed-Wing Aircraft Flyaway Costs

a. Development of CER. The cumulative average flyaway costs[4] and quantities of 14 aircraft that were designed for fighter and attack missions were normalized for a production quantity of 400 aircraft. Included are the F-4, F-5, F-14, F-15, F-16, F-18, F-100, F-101, F-102, F-104, F-105, F-106, F-111 and A-10 (See Table 1).

The normalized costs were then regressed against various (additive and multiplicative) combinations of the aircraft characteristics. Total thrust, DCPR weight, speed, thrust/DCPR

[4]Department of Defense Instruction 5000.33 dated August 15, 1977 [21] states that "flyaway is used as a generic term related to the creation of a usable end item of hardware/software." Flyaway cost includes: "elements of Major System Equipment (such as basic structure, propulsion, electronics, including Government Furnished Equipment, etc.), System/Project Management, and System Test Evaluation."

weight and time (IOC date) were examined for the fighter and attack aircraft CER. The CER selected for fighter and attack aircraft is a power function of DCPR weight, speed, and time:

$$FLY = 0.194\left(\frac{DCPR}{1000}\right)^{0.963}\left(\frac{(SP)}{100}\right)^{0.760}(1.034)^{IOC-78}$$

where

FLY = Cumulative average flyaway cost at 400 aircraft in millions of FY 1985 TOA dollars.

DCPR = DCPR weight in pounds.

SP = Maximum speed at best altitude in knots.

IOC = Initial Operational Capability calendar year, last two digits.

Note that the estimated cost increases with time at a compound rate of three percent per year; e.g., for two aircraft with the same weight and speed, but with IOC years of 1968 and 1978, the estimated flyaway cost of the former is 74 percent of that of the latter. The degree of fit between estimated and actual cumulative average cost at 400 aircraft is shown in Figure 13 for the 14 fighter and attack aircraft.

The fighter and attack CER was applicable for estimating other types of fixed-wing aircraft with the exception of (1) heavy tankers (DCPR weight $\geq$ 50,000 pounds) and (2) electronic warfare, early warning and command and control aircraft (EW^2C^2). Average cost factors were developed to adjust the CER estimates for these two types. For a given weight, speed, and IOC year, the estimated cost of a heavy tanker is 41 percent, and the estimated cost of an EW^2C^2 aircraft is 167 percent of the estimated cost of a fighter aircraft. Figure 14 illustrates the degree of fit between estimated and actual cumulative average cost at 400 aircraft of the non-fighter and non-attack aircraft on a linear scale.

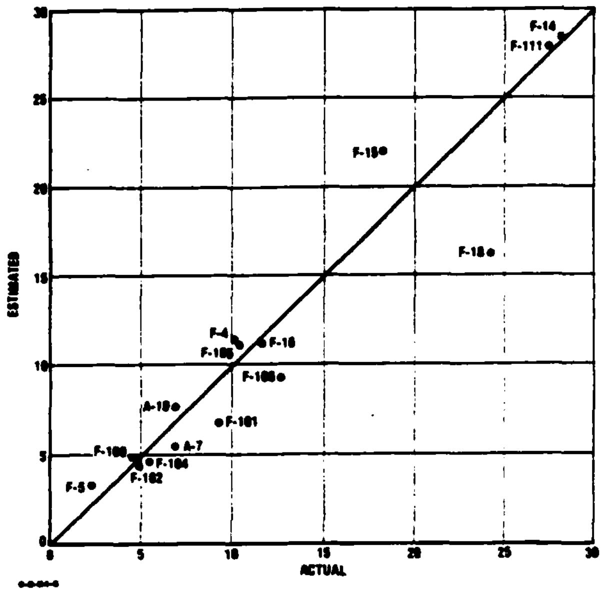

Figure 13. FIXED-WING FIGHTER & ATTACK AIRCRAFT FLYAWAY COST: ESTIMATED VS. ACTUAL--BY MODEL

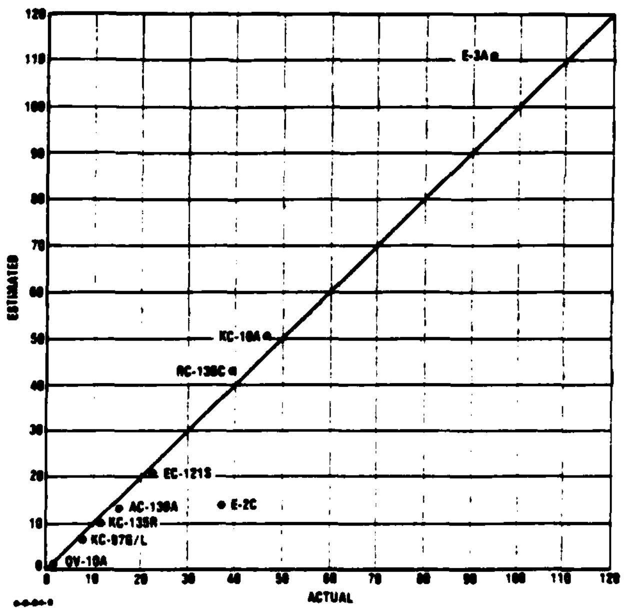

Figure 14. FIXED-WING OTHER AIRCRAFT FLYAWAY COST: ESTIMATED VS. ACTUAL--BY MODEL

b. Validation of Estimating Procedures. The actual and estimated annual aggregated flyaway costs of 18 fixed-wing aircraft are displayed in Figure 15. The estimating procedure for fixed-wing aircraft annual aggregate flyaway costs produced estimates having trends, turning points and magnitudes that were representative of actual costs.

2. Rotary-Wing Aircraft Flyaway Costs

a. Development of CER. The cumulative average flyaway costs and quantities of the following 17 helicopters were collected: OH-23, TH-13, OH-13, OH-58, OH-6, UH-1, AH-1, AH-1S, CH-46, CH-3, UH-60, AH-64, AH-1T, CH-47, CH-53 A/D, CH-54, and CH-53E. Only attack, observation, and electronic warfare helicopters were included as tactical combat aircraft. However, in order to obtain more data points trainer, utility, and cargo helicopter programs have been included in the data base. For each helicopter, the cumulative average flyaway costs were normalized at a production quantity of 400 helicopters (see Table 4).

The normalized costs were then regressed against various combinations of empty weight, DCPR weight, total shaft horsepower, speed, time (IOC date) and a dummy variable representing attack helicopters. The CER without the time term provided a closer match of estimated cost to actual flyaway cost. Accordingly, the following CER was used in developing helicopter flyaway costs:

$$FLY = 2.6(10)^{-3}(SHP)^{0.93}$$

where

FLY = Cumulative average flyaway cost at 400 aircraft in millions of FY 1985 TOA dollars.

SHP = Total maximum shaft horsepower.

Figure 16 illustrates the degree of fit between estimated and actual cumulative average cost at 400 aircraft of the 17 helicopter programs on a linear scale.

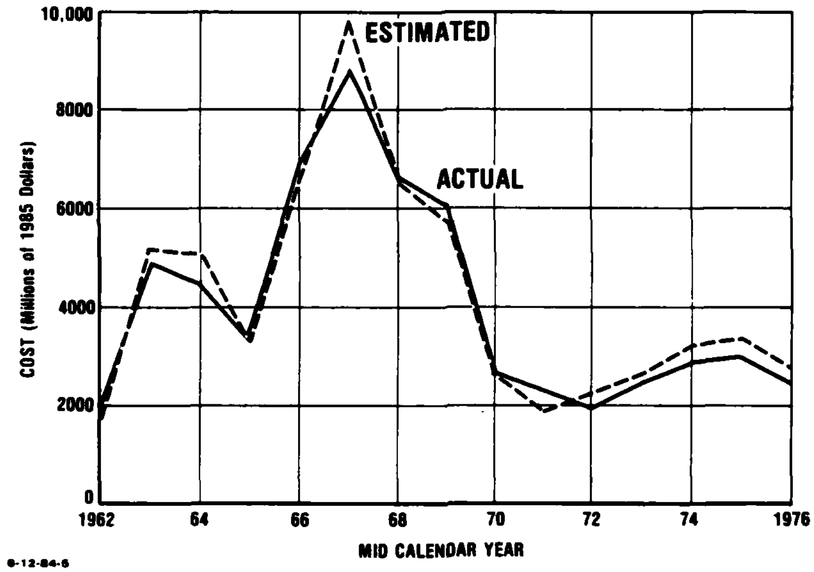

Figure 15. FIXED-WING OTHER AIRCRAFT FLYAWAY COST: ESTIMATED VS. ACTUAL--COMPOSITE, 1962-1976

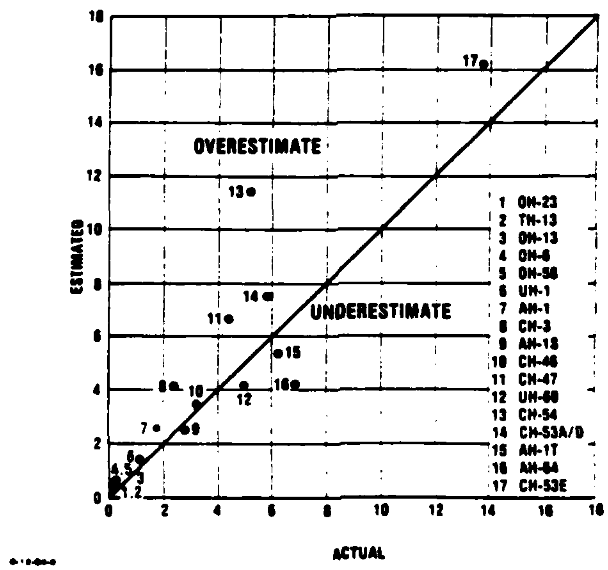

Figure 16. ROTARY-WING AIRCRAFT FLYAWAY COST: ESTIMATED VS. ACTUAL--BY MODEL (Millions of 1985 dollars)

b. Validation of Estimating Procedure. The actual and estimated annual aggregated flyaway costs of four rotary-wing aircraft (including one projected aircraft) for which the necessary cost data were available are shown in Figure 17. The estimating procedures for rotary-wing aircraft annual aggregate flyaway costs produced estimates having trends, turning points and magnitudes that were representative of the actual costs.

3. Aircraft Procurement Costs

a. Development of Procurement-to-Flyaway Cost Ratios. Estimated flyaway costs were converted into estimated procurement costs through the use of Service-peculiar, procurement-to-flyaway cost ratios. Relationships more elaborate than ratios were excluded to eliminate the need to allocate fixed cost components or to compensate for non-linear relationships.

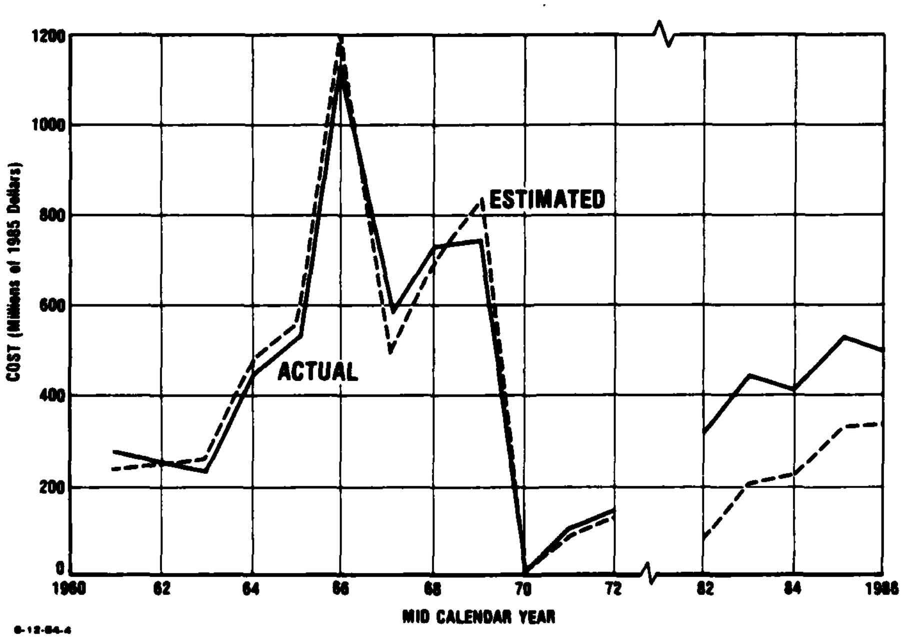

Figure 17. ROTARY-WING AIRCRAFT: ACTUAL VS. ESTIMATED ANNUAL FLYAWAY COST--COMPOSITE, 1961-1972, 1982-1986

Navy/Marines and Air Force. Data were not readily available to determine the direct relationship between annual procurement and flyaway costs; therefore, the ratio was developed in three steps:

1. The total actual weapon system costs of selected samples of fixed-wing aircraft were divided by the corresponding total actual flyaway costs. The weapon system/flyaway cost ratios average 1.17 for the Navy/Marines, and 1.16 for the Air Force.

2. The total aircraft procurement appropriation for Navy/Marine Aviation, and Air Force tactical aircraft was divided by the corresponding total actual weapon system cost over the time periods for which data were available. The procurement/weapon system cost ratios were 1.60 for the Navy and Marines, and 1.83 for the Air Force.

3. The procurement/flyaway cost ratios were determined by multiplying the two component factors. The Navy/Marines ratio was (1.17)(1.60) = 1.88.[5] The Air Force ratio was (1.16)(1.83) = 2.12.

Army. The ratio of Army Aviation annual procurement/flyaway costs selected for our estimate was 1.62. The figure was the average for 1964-1985, excluding 1972-1975 when funds for buying new helicopters (i.e., flyaway) were less than $50 million. Including figures for those years would clearly distort the estimate.

b. Validation of the Factors. Plots of the actual and estimated procurement costs for each Service are shown in Figure 18. The congruence of the curves is an indicator of how well the estimated factors converted actual flyaway and

[5]Apparent discrepancy is due to rounding.

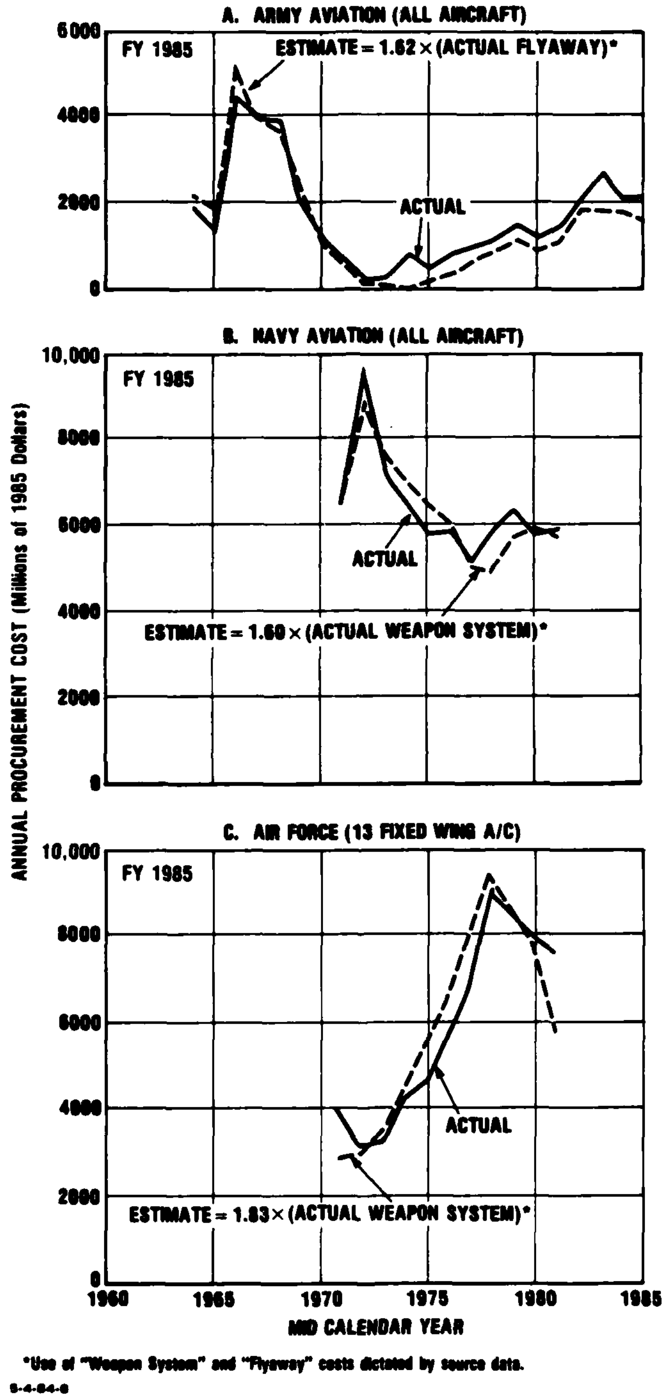

Figure 18. ACTUAL VS. ESTIMATED ANNUAL PROCUREMENT COST, BY SERVICE, 1960-1985

weapon system costs to estimates of the procurement costs. The estimates closely matched the turning points and the medium and long term trends of the actual procurement costs.

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